I have sketched merely the high spots of rubber's place in modern civilization. And much more is to come as we develop new uses for rubber. We know a comfort and perfection of living such as no other age has had. Much of the pattern of our modern scheme traces directly to the tenacity and faith of Charles Goodyear. He followed his dream through the vicissitudes of poverty and ill health. He endured public derision. He suffered the humiliation of prison and continued with his experiments even while confined in a debtor's cell.

Wise friends counseled him that it could not be done and then, in disgust, withdrew their friendship as he persisted. History records few men of his spiritual fortitude, and it is inspiring to realize that his sacrifices were not in vain. When he finally discovered the process of vulcanization, he made rubber an obedient servant which softens the harshness of our lives, protects our health and safety, speeds us on our travels, and enhances the productive value of our time on earth. It is indeed fitting that we should honor the memory of this truly great man.

LOOKING FORWARD IN RESEARCH

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I AM GLAD to pay my tribute to that great industrial pioneer, Charles Goodyear, and to all his spiritual descendants in the field of chemistry today, one hundred years later, who, in diverse directions but in the same spirit, find new methods and new products which create new industries, provide new jobs, and raise our standards of living.

Nine months ago I was invited to address you on this occasion. President Conant was to speak on the subject of chemistry in the rubber industry, and I was asked to speak on applications of physics in the rubber industry. I believe in being a good soldier, and besides nine months was a long way ahead. So I agreed to make the address. Privately, however, I said to myself, "What I don't know about physics in the rubber industry would fill volumes." I did know that physical controls of temperature were important, and that physical properties of elasticity and resistance to abrasion were significant. I knew that rubber has the anomalous property of becoming warm when it is stretched and cooling when it is compressed. Thus with the aid of a few rubber bands manipulated between the lips of a clasp, this property forms an elegant and cheap illustration of Clapeyron's equation. I knew that my colleague, Professor Warren, had used x-rays to find out a good deal about the peculiar arrangement of atoms in the rubber molecule. Another colleague, Professor Hauser, knew more about rubber than I could ever hope to learn. So I secured from him a good list of references and started to spend my spare time reading the interesting story of rubber, hoping to find out what the physicists have had to do about it.

I mention this point with some feeling, because I recollect an episode a dozen years ago when some physicists associated with the rubber companies presented their grievance to the American Physical Society; there was no recognized category of physicists in that industry and they had to call themselves chemists in order to have any standing in their community. So I started to do my homework of reading.

About that time a change in this program was suggested—namely, that President Conant should talk about what research in chemistry has done in the past for the rubber industry, and that I should talk about what we may look forward to in research. This change immediately appealed to me. In the first place it removed my inferiority complex at being a physicist instead of a chemist; in the second place, the future looks exceedingly large and long, and I thought I could find something in it to talk about; in the third place, if I get the future wrong, you could not prove it on me until long after I and my speech are forgotten.

BUT even with this new subject, I had to read, this time not books, but the future. Now reading the future is an interesting subject and has had an interesting history. All grades of forecasting, from hocus pocus and racket to art and science have coexisted as part of man's struggle for a more satisfying life. Prophecy flourished with the soothsayers of Egypt and the oracles of Greece; it lost none of its growth in the hands of the astrologers of the Middle Ages; it is practiced today by tipsters, weather prophets, investment counselors, and a host of similar services. But the immediate problem before me was to decide on the exact form of hocus pocus or art which I should employ in disclosing the future of research.

Perhaps by a process of association the answer to my problem came by thinking first of chemistry, then of du Pont, and then of an incident in a visit which I was privileged to make a couple of years ago to the wonderful greenhouses of Pierre du Pont near Wilmington. There Mr. du Pont showed me three beautiful large spheres, and told me that two of them were of quartz crystal and had been used by the crystal gazers of India to concentrate their thoughts as they gazed into the future. The third sphere was made of the new transparent plastic which had recently been developed by the du Pont Company. Mr. du Pont challenged me to tell him, by inspection, which of the three spheres was not quartz crystal. So, as I was thinking about my address, it occurred to me to ask Mr. du Pont for the loan of a sphere of this material so that I, like the soothsayers of India, might gaze into it and try to read the future of research.

I see in this sphere a story of cooperative research by many investigators who selected what they needed from the voluminous records of former scientific discoveries, often apparently unrelated to one another. They coordinated this knowledge, added to it, developed an art of manipulation suited to their needs and kept their imagination alert to the possibilities of practical use. Some stages of the work seemed at the time to be insignificant; occasionally some step appeared to open up new pioneering territory; all put together and properly coordinated, these efforts gave us a valuable new product.

This sphere tells me that the same essential story, differing only in its details, describes the development of the rubber

industry. Charles Goodyear had some background of previous experience to start with, but he made a pioneering step into new territory when he heated crude rubber with sulfur. Subsequently accelerators and controls improved the process and the product. The practical importance of rubber has stimulated research to develop substitutes which may have even better properties than rubber for some of the uses to which rubber is put. Undoubtedly the scientific approach to rubber has stimulated the study of polymerization and the development of plastics. Important as these developments have been in themselves, they have become far more important as they have been coordinated with other developments in quite different fields, such as those in mechanical engineering and metallurgy which have produced such gigantic new industries as the automobile, or such as those involving physics and electrical engineering which have utilized rubber insulation in so many important electrical devices.

WHILE we recognize the fact that science in the sense and scope which we see about us today is a modern development, nevertheless this story which I read in the sphere has nowhere been described more beautifully and adequately than in the words of Aristotle: "The search for Truth is in one way hard and in another easy, for it is evident that no one can grasp it fully nor miss it wholly; but each adds to the knowledge of Nature and from all the facts assembled there arises a certain grandeur."

Why is it that, although Aristotle so truly grasped the road to the knowledge of nature, it is only within recent generations that we have come to what is now called the "scientific era"? Undoubtedly many factors have conspired in this development. One of them has been the relief from superstition and from religious authority and dogmatism which has come with increasing knowledge of nature. Another has been the general acquirement of manual skills which came about largely through the influence of the Benedictine monks in the Middle Ages; they taught the dignity of human labor which previously had been considered, in high circles, to be proper only for slaves and serfs. But I believe that there is another important factor which has its bearing upon the future of scientific research and which can be illustrated as follows:

Imagine that we know only one fact of nature. The probability that we will be able to utilize this one fact to accomplish some given desire is very small. If, however, we know two facts of nature, the probability that we can use them is considerably multiplied, because we might use either one separately or we might use the two in combination. Similarly, if we know three or four facts of nature, the number of combinations gives us greatly increased opportunity of finding some way of utilizing these facts advantageously. Roughly speaking, the possibility for advantageous use of our knowledge increases somewhat as the square of the number of facts of which our knowledge is comprised. This simple, logical situation provides an explanation of the increasingly rapid application of science to the problems of life. We now know so many of the laws and relationships between matter and energy and we know so much about the properties of various materials that there is enormous scope and latitude in our search for those products or processes which will enable us to have the things and do the things which we desire in an advantageous fashion. Reciprocally, these practical applications of scientific knowledge have given an enormous impetus to the search for new knowledge. Because of this logical situation, we can look forward with certainty to a continually accelerated rate of scientific discovery and of the practical applications of science in invention and engineering. If there is any limit to this acceleration it probably lies in the limited capacity of our poor human minds to grasp and to deal effectively with the mass of information which is potentially available for our use.

NOW let me be a little more specific as I "look forward in research." I cannot tell what the new research developments will be because I do not know. In fact, it has always appeared to me that no research really deserves the name if its result can be foretold when it begins. Although I cannot tell specifically what the new research developments will be, I do think that it is possible to speak with a good deal of assurance with regard to their general nature and significance. Perhaps as good a way as any to do this is to think of research in its relation to the great problems with which we are struggling in this day and generation.

At the present moment undoubtedly the greatest concern of the world is war and threat of war. A good deal has been said about the ways in which science has been applied to make warfare more destructive, just as science has also been applied to bring about a certain compensating degree of protection against new weapons. But there is one possibility in science which seems to be far more significant then these—namely, the use of science to remove some of the major causes of war.

In so far as wars are caused by the natural "cussedness" of human nature, science can contribute, if at all, only indirectly. It can probably not do much toward removing the desire which some men have for great domination. It cannot remove ambition and envy from the human breast. But in so far as wars may be induced by economic considerations, science may do much to remove the causes.

One of the earliest incentives to war was the invasion of one country by another for the purpose of loot. Later as we became more civilized, this took the form not so much of loot as of the control of population for the purposes of taxation and of exploitation of labor and of natural resources. This is all part of the old primitive instinct of animals and men to secure the good things of life by taking them from someone else.

Science, however, has given mankind a method of gaining the good things without taking them from someone else and without working inordinately long and hard to produce them. Discovery and development of the good things of life by science, engineering, and invention are a far more certain and productive source than organized loot and robbery. To the extent, therefore, that great groups of people, such as nations, can be induced to support technological development directed toward these ends, to that extent can they satisfy their desires without recourse to war.

More specifically, many nations have felt the urge to conquest in order to secure to themselves an assured supply of various materials which are necessary to the nation's economy. For example, Great Britain needs oil for her navy and food for her population, which cannot be produced in the British Isles. Germany and Japan need rubber, foodstuffs, and mineral resources. Even the United States, richest of all nations in its mineral resources, is inadequately supplied with such important materials as rubber, tin, and tungsten. Does national safety force these nations to conquest in order to assure themselves of these commodities?

The record which I read in the crystal sphere justifies the assertion that the necessities of national economies can be taken care of by scientific research at a cost far less than that of a major war and within a time far less than that in which the effects of a major war would still be felt. At the same time this could be done not only without hurting anyone but with great indirect benefit to all concerned. Let me give a few examples.

The time will surely come in the not too distant future when a satisfactory motor fuel can be produced from coal at a cost which is not too far out of line with that of petroleum products. When this happens Great Britain, for example, will no longer be critically dependent upon the Persian oil fields nor

will we be so much worried about Japan's efforts to secure a foothold in Mexico. When substitutes for rubber are produced which are satisfactory for automobile tires and which can be produced at a reasonably competitive price, then one of the great causes of anxiety and international haggling will have been removed. Perhaps the new development of "chemical agriculture" in which farm products are produced without soil by planting them so that their roots are bathed in appropriately nutritive chemical solutions can be developed to remove the fear of food shortage which now causes so much anxiety in several nations and will at the same time provide a diet which will be a distinct improvement on that now customary. The development of suitable lacquers as substitutes for tin in the coating of containers for canned foods will make the United States less anxious about its access to the Bolivian tin supply. Or perhaps improved methods of extraction from our existing but rather poor tin deposits may accomplish the same result. To the extent that science can produce these materials or suitable substitutes, to that extent will be removed almost the only basis for war which can be intelligently argued for at the present time.

UNDOUBTEDLY the second great problem which faces our nation most critically today is the problem of unemployment. There has been much progress in the past decade in clarifying the public mind with regard to the relation of science to this problem. I will therefore not discuss it further except to present three references.

Charles F. Kettering wrote a couple of years ago: "We have in this country an excess of materials, an excess of money, and an excess of men, all of which to a primitive mind like mine means that we haven't any projects to work on. We think we are technologically ahead instead of being technologically behind; and if we could get out of our minds the idea that we know a lot about everything and realize that the whole thing is ahead of us, then we would have a shortage of labor in no time."

A notion of what science and technology have meant to the world in the matter of employment can be illustrated vividly by contrast if we read Macaulay's "History of England." We find there just before the scientific age that one third of the entire population was on poor relief. We get there a picture of the dismal and desperate surroundings and the drudgery in the life of the common people. At present, although there is still serious unemployment, we can point to the fact that a much larger population is being supported than in the time of which Macaulay wrote, and we can see that the standard of living has been enormously improved, even for those who are at present unemployed.

The third quotation refers specifically to the chemical industry and is particularly important because this is one of the industries which is very modern and entirely due to research. Let me quote a paragraph from a recent issue of *Industry*, based on records from the United States Bureau of Labor Statistics and the National Industrial Conference Board:

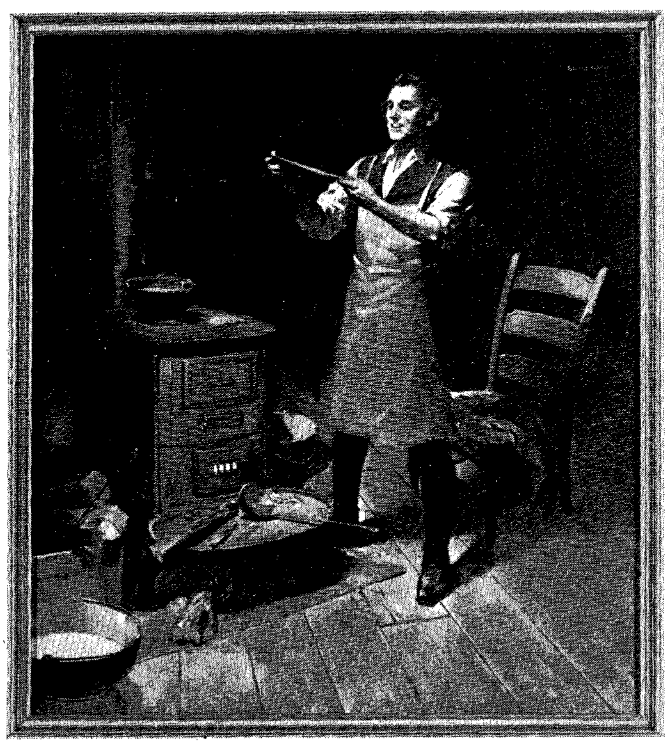
"Employment today in the chemical industry is 27 per cent higher than in 1929 although manufacturing generally is still about 5 per cent lower than the 1929 peak. The chemical industry's average hourly wage, also average weekly wage, is 15 per cent higher than for all manufacturing. The chemical factory worker earns on the average $31 a week compared with an average of $26 a week for all manufacturing industries."

The third great question facing all of us individually and in groups today is the question of profit. Who is going to pay the bill? This applies not only to Mr. Average Citizen but also to great business enterprises and to practically every governmental unit—municipal, state, and federal. Intimately related to this question is the question of taxation. What is there to be taxed further?

Both logic and experience indicate that the only true source of wealth is production, and that the only way substantially to increase production is to increase the number of desirable things which are to be produced and to employ to an even greater extent the forces of nature, harnessed by suitable mechanical devices, to produce them. I believe that a portion of the cost of war, if suitably directed in research, could remove many of the basic causes of war. Similarly I believe that a portion of the money spent for relief of employment by mortgaging our future in debt could, if properly directed toward research in the development of desirable new products and processes, provide the desired employment and at the same time create the profits to pay the taxes which only can remove the enormous debt we have now incurred.

This list of problems could be greatly extended if time permitted. We have problems of safety and security, opportunity for education and recreation, and many others. To all of them science has a contribution to make. The fact that the needs exist and that science has demonstrated its ability to contribute to the solution of these needs gives adequate basis for the assertion that we will see science making substantial contributions to the solution of these problems as we go forward in research.

The most fitting conclusion to these remarks would be a quotation from Pasteur, since it appears to bear so directly upon the thoughts and the problems of our present generation: "In our century science is the soul of the prosperity of nations and the living source of all progress. Undoubtedly the tiring discussions of politics seem to be our guide. Empty appearances! What really leads us forward is a few scientific discoveries and their application."



Artist's Conception of Goodyear's Discovery of the Vulcanization Process

Courtesy, The Goodyear Tire & Rubber Company